Design of Shallow Foundations

NCHRP 368

Chapter 7

pages 49 to 56

The bearing resistance and settlement behavior of shallow foundations can be calculated in two manners:

1. Indirect methods that use conventional soil mechanics methods and parameters:
   1. s_u, ϕ', E', E_u, and c_v determined from correlation with q_t, f_s, u_2, v_s and pore pressure dissipation tests.
   2. c_c and c_r determined from lab consolidation tests.
2. Direct methods that incorporate the measured cone tip resistance (q_t) in the formulae.

Indirect methods for bearing resistance and sliding analysis of shallow foundations

- Analysis of general shear, local shear and punching failure of a one layer foundation condition
- Analysis of the general shear failure of a two layer foundation condition
- Sliding resistance

Direct methods for bearing resistance analysis of shallow foundations

- Schmertmann (1978a) in NCHRP 368
- Meyerhof (1956) in LRFD BDS
- Tand (1986) in NCHRP 368

$$q_R = (\phi_b)\,(q_n)$$

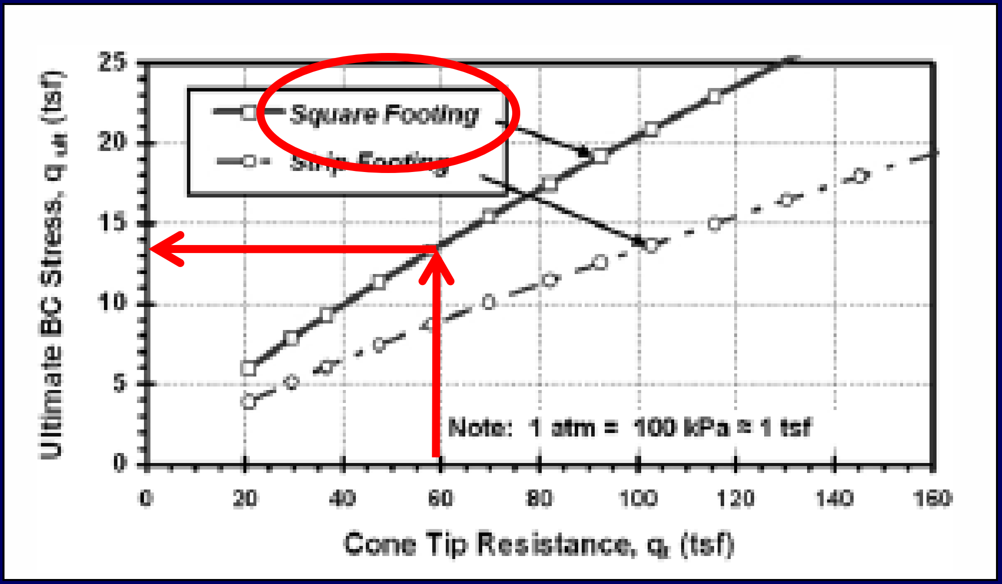
ϕ_b = 0.50 is recommended in LRFD BDS

Schmertmann method for bearing capacity of spread footings on cohesionless soil

The following footing width and embedment conditions must be met:

When B > 3 feet, the embedment D_f >= 4 feet

When B <= 3 feet, the embedment D_f >= 1.5 + 0.5(B) in feet



Schmertmann method for bearing capacity of spread footings on cohesionless soil

For square footings:

$$q_n = 0.55\,(\sigma_{atm})\,(q_t/\sigma_{atm})^{0.785}$$

where $\sigma_{atm} = 1.0$ TSF

For strip footings:

$$q_n = 0.36\,(\sigma_{atm})\,(q_t/\sigma_{atm})^{0.785}$$

where $\sigma_{atm} = 1.0$ TSF

Meyerhof method for bearing resistance of spread footings on cohesionless soil (1956)

$$q_n = \overline{q_c}\,(B'/40)\,((C_{wq})\,(D_f/B') + C_{w\gamma})$$

$\overline{q_c}$ = average cone tip resistance within a depth of B below the bottom of the footing

B' = effective footing width (feet)

D_f = footing embedment (feet)

C_{wq} and $C_{w\gamma}$ = groundwater correction factors

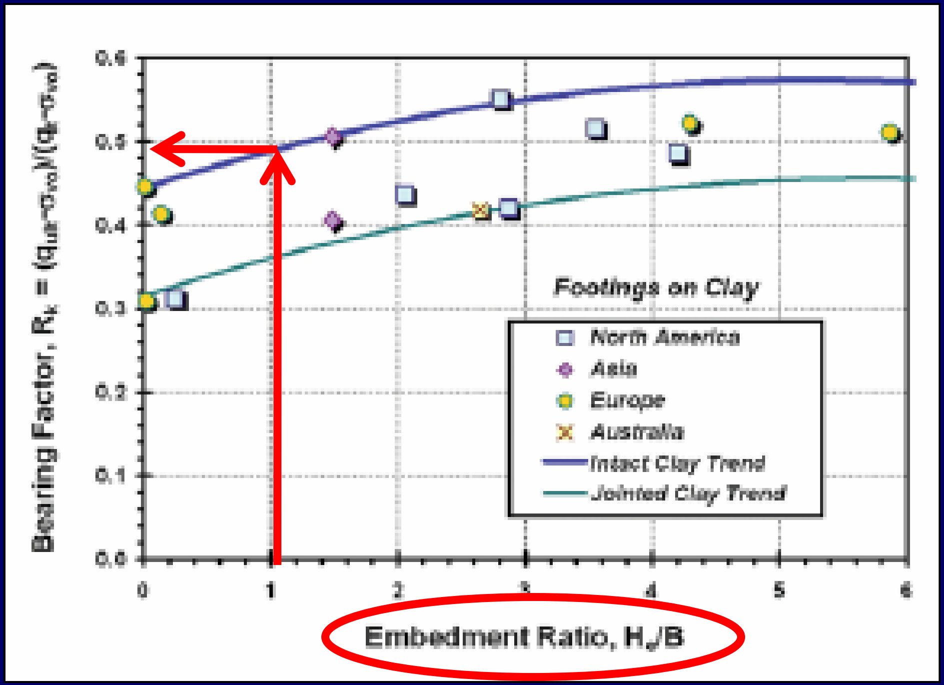
D_w	C_{wq}	$C_{w\gamma}$
0.0	0.5	0.5
D_f	1.0	0.5
> 1.5 (B) + D_f	1.0	1.0

Meyerhof method for bearing resistance of spread footings on cohesionless soil

- Simple calculation using cone tip resistance data.
- Conservative results for footings narrower than 1.5 feet.
- Reasonable results for footings between 1.5 and 4 feet.
- Unconservative results for footings wider than 4.0 feet.
- Useful method for buildings foundations, but should be used in conjunction with at least two other analytical procedures when sizing a bridge foundation.

Tand method for bearing resistance of spread footings on cohesive soil

$$q_n = \sigma_{v0} + R_k\,(q_t - \sigma_{v0})$$



H_e = depth of embedment
B' = effective footing width

Example calculations for bearing resistance of spread footing on cohesionless soil

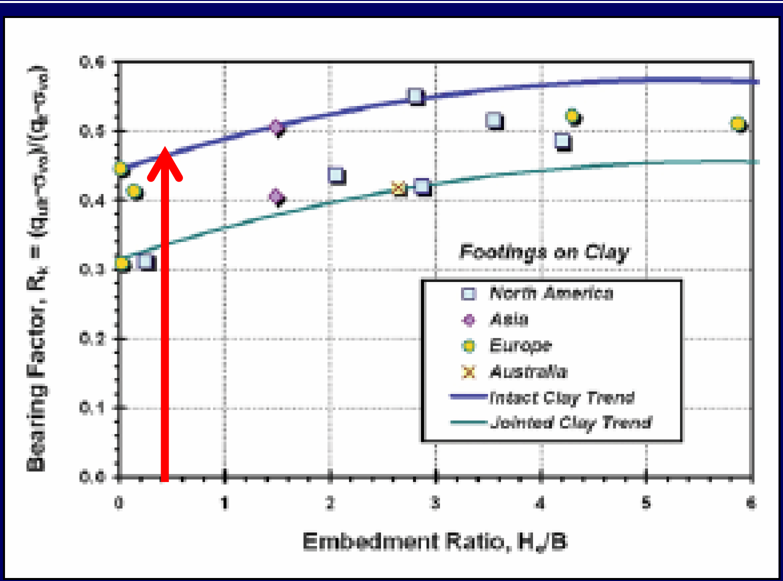
- Geometric conditions
  - $B' = L' = 10$ feet
  - $D_f = H_e = 5$ feet
- Foundation conditions
  - $q_t = 70$ TSF
  - $D_w > 1.5\,(B) + D_f$

- Schmertmann from chart:
  - $q_n = 15$ TSF
  - $q_R = \underline{7.5\text{ TSF}}$
- Schmertmann calculation:
  - $q_n = 0.55\,(\sigma_{atm})\,(q_t/\sigma_{atm})^{0.785}$
  - $q_n = 0.55\,(1.0)\,(70/1)^{0.785} = 15.4$ TSF
  - $q_R = \underline{7.7\text{ TSF}}$
- Meyerhoff calculation:
  - $q_n = q_c\,(B'/40)\,((C_{wq})\,(D_f/B') + C_{w\gamma})$
  - $q_n = 70\,(10/40)\,((1.0)\,(5/10) + 1.0) = 26.2$ TSF
  - $q_R = \underline{13.1\text{ TSF}}$

Example calculation for bearing resistance of spread footing on cohesive soil

- Geometric conditions
  - $B' = L' = 10$ feet
  - $D_f = H_e = 5$ feet
- Foundation conditions
  - $q_t = 70$ TSF
  - $D_w > 1.5\,(B) + D_f$

- Tand calculation:
  - $q_n = (\sigma_{v0}) + R_k\,(q_t - \sigma_{v0})$
  - $R_k = 0.46$ from chart below
  - $q_n = (12.5)(0.110/2) + 0.46(70 - (12.5)(0.110/2)$
  - $q_n = 4.1$ TSF
  - $q_R =$ <u>2.0 TSF</u>



Indirect analysis methods using CPT data for computation of foundation settlement

- For cohesionless soils:
  - The immediate settlement of both saturated and unsaturated <u>cohesionless soils</u> can be calculated using the ‘approximate nonlinear method’ and <u>drained</u> soil parameters.
- For cohesive soils:
  - The immediate settlement of both saturated and unsaturated <u>cohesive soils</u>, where the applied soil stress is less than σ_p’, can be calculated using the ‘approximate nonlinear method’ and <u>undrained</u> soil parameters.
  - The recompression portion of consolidation settlement of saturated <u>cohesive soils</u>, where the applied soil stress is less than σ_p’, can be calculated using the ‘approximate nonlinear method’ and <u>drained</u> soil parameters.

‘Approximate nonlinear method’ for calculating the immediate settlement of spread footings founded on unsaturated or saturated cohesionless soil (drained response)

$$\boxed{s_c = q\,(B')\,(I_H)\,(1 - (\nu')^2)\,/\,E'}$$

s_c = displacement below the center of the footing

q = Service Limit State Load divided by the effective footing area

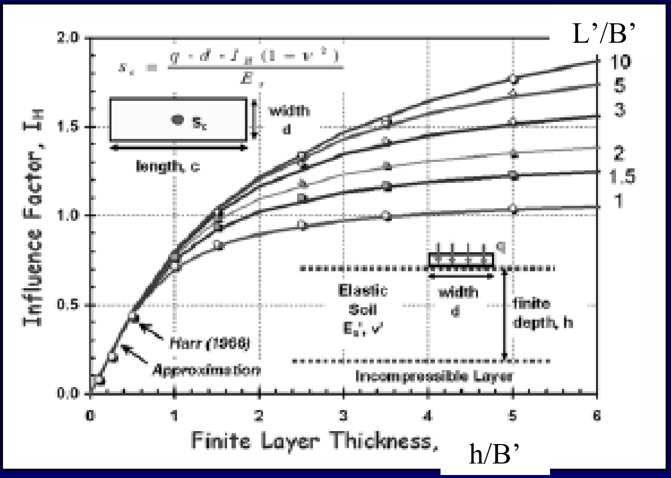
B' = effective footing width (feet)

I_H = influence factor

ν' = poisson’s ratio for drained conditions = 0.20

E' = Young’s modulus for drained conditions

$E' = E_0\,(1 - (q\,/q_n)^{0.3})$ where E_0 is the drained small strain Young’s modulus determined from v_s and ν'



'Approximate nonlinear method' for calculating the immediate settlement of spread footings founded on unsaturated or saturated cohesive soil (undrained response)

The total effective stress at mid-height of the soil layer is the sum of the overburden stress and the footing stress. Do not use this method for the portion of the stress that exceeds σ_p'. When $\sigma_{v0}' + \Delta\sigma_v' > \sigma_p'$ the stress in excess of σ_p' causes long term settlement, which is a drained plastic behavior.

$$s_c = q\,(B')\,(I_H)\,(1 - (\nu_u)^2)\,/\,E_u$$

s_c = displacement below the center of the footing
q = Service Limit State Load divided by the effective footing area, not to exceed σ_p'
B' = effective footing width (feet)
I_H = influence factor
ν_u = poisson's ratio for undrained conditions = 0.50
E_u = Young's modulus for undrained conditions
$E_u = E_0\,(1 - (q/q_n)^{0.3})$ where E_0 is undrained small strain Young's modulus determined from v_s and ν_u

'Approximate nonlinear method' for calculating a portion of the consolidation settlement of spread footings founded on saturated cohesive soil (drained response)

This calculation is for the settlement that occurs in response to the portion of the total effective stress that is less than σ_p'. The calculation shown below provides the same result as using the recompression index to determine the portion of consolidation that results from stresses that follow the recompression portion of an e-log p curve.

$$s_c = q\,(B')\,(I_H)\,(1 - (\nu')^2)\,/\,E'$$

s_c = displacement below the center of the footing

q = Service Limit State Load divided by the effective footing area; the portion that exceeds σ_p'

B' = effective footing width (feet)

I_H = influence factor

ν' = poisson's ratio for drained conditions = 0.20

E' = Young's modulus for drained conditions

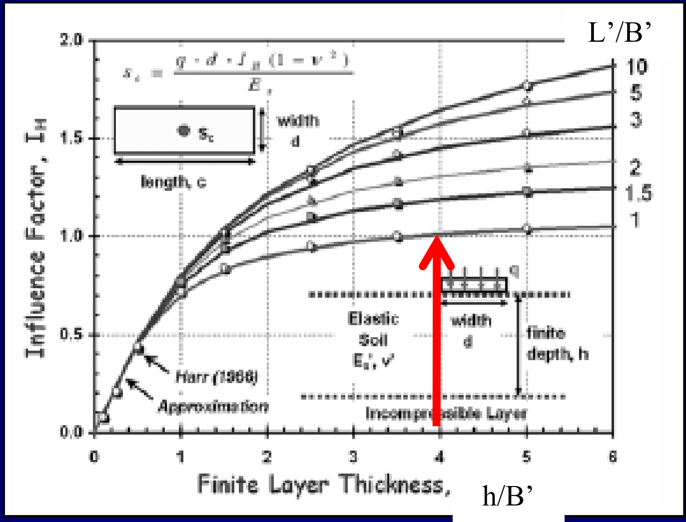
E' = $E_0\,(1 - (q/q_n)^{0.3})$ where E_0 is drained small strain Young's modulus determined from v_s and ν'

Indirect analysis methods for computation of the long term/consolidation settlement of cohesive soil

- Coefficient of consolidation for time-of-consolidation calculations can be determined from the analysis of CPT pore pressure dissipation data.
- Vertical drainage path distances can be assessed by stratigraphic interpretation of CPT data.
- Compression Index and Recompression Index can <u>not</u> be determined from CPT data. Laboratory consolidation tests of undisturbed soil samples are required.

Calculation of the elastic settlement of a spread footing on cohesionless soil using the approximate nonlinear method

- Geometric conditions
  - $B' = L' = 10$ feet
  - $D_f = H_e = 5$ feet
- Foundation conditions
  - medium dense sand
  - $q_t = 70$ TSF
  - $v_s = 820$ ft/sec
  - $D_w > 1.5\,(B) + D_f$



$$s_c = q\,(B')\,(I_H)\,(1 - (\nu')^2) / E'$$

s_c = displacement below the center of the footing
q = Service Limit State Load divided by the effective footing area = 3.0 TSF = 6.0 ksf
B' = effective footing width (feet)
I_H = influence factor = 1.0
ν' = poisson's ratio for drained conditions = 0.20
E' = Young's modulus for drained conditions
$E' = E_0\,(1 - (q/q_n)^{0.3})$ where E_0 is the drained small strain Young's modulus determined from v_s and ν'
$E_0 = 2\,(\rho/g)\,(v_s)^2\,(1 + \nu')$
$E_0 = 2\,(0.130/32.2)\,(820)^2\,(1 + 0.20) = 6600$ ksf
$E' = 6600\,(1 - (3.0/18.0)^{0.3}) = 2760$ ksf

$$s_c = 6.0\,(10.0)\,(1.0)\,(1 - (0.20)^2) / 2760$$

s_c = 0.021 feet = <u>0.25 inch</u>

Summary and recommendations

- Bearing resistance of shallow foundations:
  - Indirect methods using correlation derived conventional soil parameters for strength and unit weight
  - Direct methods using q_t values
    - Schmertmann for cohesionless soils
    - Tand for cohesive soils
- Settlement calculations for shallow foundations:
  - Indirect method based on approximate nonlinear theory using correlation derived E’ and E_0 can be used to determine elastic settlement and the recompression portion of consolidation.
  - Virgin compression of the soil can only be analyzed with the compression index (C_c) determined from lab test results.
  - There are no direct methods available for settlement analysis.

Exercise 3:
Calculate the nominal bearing resistance of a spread footing